Ransome, F. Leslie
1895.

Prof. C. D. Walcott.
with the author's compliments.

Chas. D. Walcott.

UNIVERSITY OF CALIFORNIA
Bulletin of the Department of Geology
Vol. 1, No. 10, pp. 301-312, Pl. 17. ANDREW C. LAWSON, Editor

ON

LAWSONITE

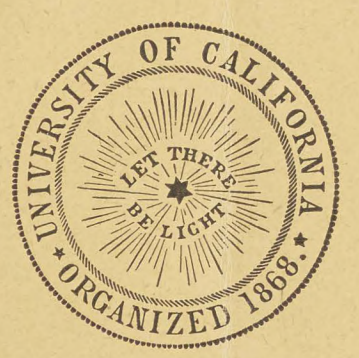
A New Rock-Forming Mineral,

FROM

The Tiburon Peninsula, Marin Co., Cal.

BY

F. LESLIE RANSOME,
Fellow in the University of California.



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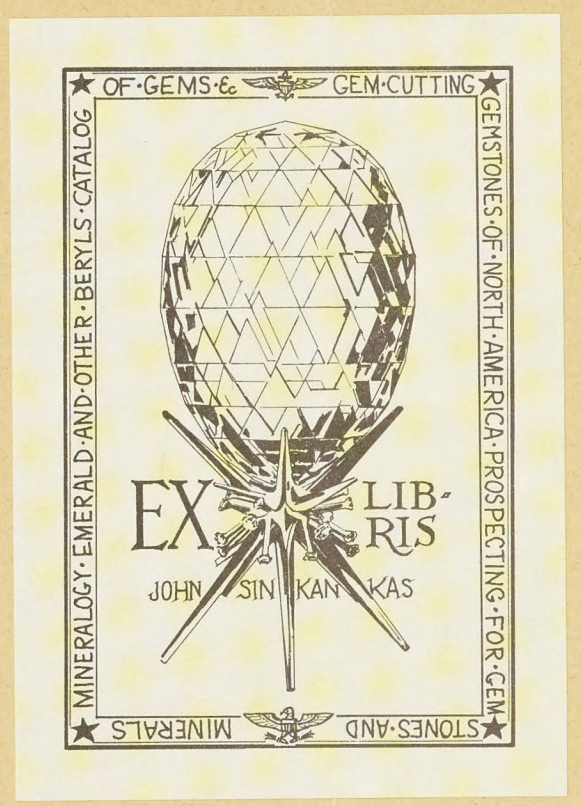
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THE TIBURON PENINSULA, MARIN COUNTY, CALIFORNIA*

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OCCURRENCE.

THE mineral for which the writer proposes the name *lawsonite*, in honor of Prof. Andrew C. Lawson, occurs as an important rock-making constituent of a rather massive outcrop of crystalline schist, which is exposed near the periphery of an extensive sheet of serpentine, on the Tiburon Peninsula, at a point about half a mile in an easterly direction from Reed Station, on the line of the San Francisco and North Pacific Railroad.

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* The writer takes sincere pleasure in according to his friend, Dr. Charles Palache, the credit of a simultaneous discovery of the new mineral here described, and in acknowledging the courtesy and generosity shown by him. Dr. Palache found the mineral in his thin sections, while making a petro-

It was first noticed in the form of white crystals projecting with rough, pitted surfaces and irregular outlines from weathered blocks of the schist, the roughness of the surface and the lack of sharp crystal boundaries being due to the presence of abundant inclusions of the various other component minerals of the schist. Besides occurring as a rock constituent, lawsonite is found in much larger crystals, generally free from noticeable inclusions, embedded in a greenish-white micaceous mineral, determined as margarite, in veins traversing the schist, and also lining or filling smaller veins and cavities, as aggregates of clear colorless crystals, associated with actinolite in delicate acicular tufts.

Crystals of lawsonite are of simple habit, the most conspicuous faces being those of the prism, basal pinacoid, and brachydome. Those which project freely into cavities have the general form shown in Plate 17, Fig. 1; those embedded in the margarite, the tabular, and extended habits of Figs. 5, 6, and 7. A thin section of the massive portion of the schist shows that the mineral encloses the glaucophane and other constituents, as ice in a pond imprisons the sticks and grains at its margins. Yet it retains somewhat its idiomorphic form, as appears when the rock is subjected to weathering. The structure under the microscope is similar to the micropoikilitic structure, but differs, of course, genetically, from the structure in igneous rocks to which that term has been applied.*

CRYSTAL FORM.

Lawsonite crystallizes in the orthorhombic system. The axial ratios $a : b : c = .6652 : 1 : .7385$ were calculated from the following angles, measured on a Fuess *Universalapparat*:—

---

graphical study of some of the schists from the Tiburon Peninsula, at the University of Munich, and upon accidentally learning through correspondence that the work embodied in the present paper was well under way, he immediately placed his observations unconditionally at the service of the writer. Such results as he was able to arrive at, with the very limited material at his disposal, and his suggestions, have been of great service in the preparation of this paper. It is gratifying to note that, in the matter of choosing a name, Dr. Palache and the writer are in perfect accord, as *lawsonite* was the entirely independent choice of both.

*G. H. Williams, Jour. Geol., Vol. I, No. 2, 1893.

$m : m = 110 : 1\bar{1}0 = 67° 16'$, and
$d : d = 011 : 0\bar{1}1 = 72° 53.5'$.

The faces of the brachydome {011} are marked by a strong striation parallel with the basal edges which renders it difficult to secure good reflections. These striations are present on the very smallest crystals that could be handled, and cause multiple and blurred signals in the goniometer. In the following table of measurements the larger variations in the observed angles must be laid to this cause, and to the difficulty of deciding just which one of a series of images is the significant one for the face. The faces of the prisms, {110} are also striated parallel with the basal edges, but less strongly than the dome faces, so that the readings are not so much interfered with.

TABLE OF ANGULAR MEASUREMENTS OF LAWSONITE.

No. of Crystal.	Angle.	No. of Readings.	Mean.	Extremes.	Calculat'd Angle.	Remarks.
1	$d : d = 011 : 0\bar{1}1$	5	72° 48.8′	72° 48′—72° 51′	.....	Three signals on each face. Read middle
4	"	5	72° 53′	72° 47′—72° 56′	.....	One signal rather ill-defined.
11	"	5	72° 19.8′	72° 17′—72° 22′	.....	Signals faint.
12	"	2	72° 53.5′	72° 52′—72° 56′	.....	Trains of signals. Read first and brightest.
13	"	3	72° 45′	72° 45 —72° 45′	.....	Trains of signals. Read first and brightest.
18	"	3	72° 54.4′	72° 54′—72° 55	.....	Double signals. Took mean of both.
18	"	2	72° 53.5′	72° 53′—72° 54′	.....	Double signals. Read brightest.
8	$m : m = 110 : 1\bar{1}0$	5	67° 16′	67° 16′—67° 16′	.....	Excellent signals.
11	$d : m = 011 : 110$	3	70° 52.6′	70° 50′—70° 55′	70° 47.4′	Signals blurred by striations.
6	$d' : m = 041 : 110$	3	58° 11.7′	58° 11′—58° 12′	58° 21.3′	Good, clear signals.
6	$d : d' = 011 : 041$	3	34° 43.3′	34° 43′—34° 44′	34° 52.2′	Good, clear signals.
10	$m : o = 110 : 001$	5	90° 0′	89° 59′—90° 3′	90° 0′	.....
20	$o : d' = 001 : 041$	1	71° 15′	.....	71° 18′	Angle observed by Palache.
21	$d' : m = 041 : 110$	....	58° 20′	.....	58° 21.3′	Angle observed by Palache.

The mineral possesses two fairly distinct habits according as it crystallizes freely in empty clefts and cavities, or in a matrix of margarite. In the former case it has the general form shown in Plate 17, Fig. 1, less often that of Fig. 2. The small face d' of the brachydome {041} Plate 17, Fig. 3, was observed on only two small crystal fragments. Crystals possessing the habit shown in Plate 17, Figs. 1 and 2, are small, generally under 5 mm. in greatest diameter. On the other hand, such crystals as occur embedded in margarite are characterized by their greater size, and by a prevailing tabular form, the basal planes being well developed, and striated strongly, parallel with the brachy-axis. Irregularly rounded, and deeply striated brachydome faces are usually present on these larger crystals, but such simple forms as Plate 17, Fig. 7, are by no means rare. A conspicuous extension of a pair of the prism faces in a horizontal direction, as in Plate 17, Fig. 6, is so constant as to be characteristic. The size of these embedded crystals is often considerable, incomplete fragments measuring as much as 5 cm. in width across the basal plane, while the length of the perfect crystal in the direction of characteristic elongation is in some cases five or six times that dimension.

Twins are common in both classes of crystals, the twinning and composition plane being the prism. A common form of twin among the large embedded crystals is shown in Plate 17, Fig. 5 and the characteristic feather arrangement of the basal striæ is diagrammatically indicated in Fig. 4. In Plate 17, Fig. 8, is shown one of the smaller crystals, with a habit intermediate between Figs. 1 and 2, twinned according to the same law.

Lawsonite has two conspicuous cleavages, a perfect cleavage parallel with the brachypinacoid {010} and a sub-perfect cleavage parallel with the basal pinacoid {001}. Sections cut parallel with the macropinacoid show these cleavages as two sets of lines cutting each other at an angle of 90°. Those parallel with $\dot{c}$ are bolder, more abundant, and more continuous than those parallel with $\bar{b}$, which are generally fine and interrupted. There is, besides these, a third and very indistinct cleavage parallel with the prism, which has not been detected macroscopically, but can be seen in basal sections under the microscope when the light is properly adjusted, as a series

of fine, generally short and scattered, lines intersecting each other at the prism angle. This cleavage is usually much better seen in such portions of crystals as exhibit a blue pleochroism presently to be described, the lines of color in such cases running parallel with, and accentuating, the cleavage cracks. Brachypinacoidal sections also show this cleavage as short, fine lines, much scattered, and intersecting the basal cleavage at 90°.

The possibility of the mineral being monoclinic was considered, but the coincidence of the axes of elasticity with the crystallographic axes, the angle of 90° between the faces of the basal pinacoid and the prism, and the symmetrical character of the interference figure, would seem to put its orthorhombic character beyond question.

OPTICAL PROPERTIES.

The axial plane is the brachypinacoid, the acute bisectrix emerging on the basal plane. It is positive in character. The orientation of the axes of elasticity is accordingly $\mathfrak{a} = \breve{a}$, $\mathfrak{b} = \overline{b}$, $\mathfrak{c} = \dot{c}$.

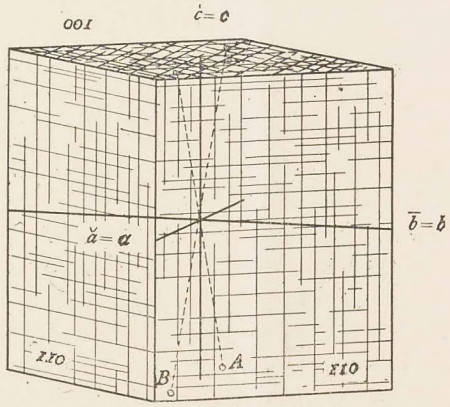

FIGURE 1. Optical scheme of lawsonite.

The acute and obtuse axial angles were measured for sodium light in cassia oil, affording the values $2H_a = 88° 27'$ and $2H_o = 103° 16'$, from which the value of $2V_a = 84° 6'$ was calculated by the usual formula:—

$$\tan V_a = \frac{\sin H_a}{\sin H_o}$$

A value for the mean index of refraction $\beta = 1.671$ for sodium light was obtained by substitution in the formula $\beta = n \frac{\sin H_a}{\sin V_a}$, where $n = 1.6053$ the index of refraction of cassia oil.

By the usual method with specially-cut prisms, the following values were obtained for the three indices of refraction for sodium light:—

$$\alpha = 1.6650$$
$$\beta = 1.6690$$
$$\gamma = 1.6840$$

from which $\gamma - \alpha = .019$ and $\frac{\alpha+\beta+\gamma}{3} = 1.6726$.

Before suitable material was obtained from which to cut prisms, the method of the Duc de Chaulnes was employed to determine α and γ for white light. The focusing was done on a large model Nachet microscope, using an attenuated wash of carmine as a signal for the bottom of the thin plate. With the greatest care this method is subject to the possibility of serious error, but the final results obtained agree fairly well with those already given for sodium light. They are:—

$$\alpha = 1.659$$
$$\gamma = 1.685$$

A thin plate cut parallel with the axial plane, and showing between crossed nicols red of the second order, was investigated by means of the *comparateur* of Michel-Levy, and the value $\gamma - \alpha = .0207$ obtained for the measure of the double refraction in white light. This agrees as closely as could be expected with the value arrived at with the prisms for sodium light.

The dispersion of lawsonite is $\rho < v$.

In certain rather thick basal sections a strong pleochroism was observed—blue parallel with $\mathfrak{a}$ and colorless, or with a slight tinge of yellow, parallel with $\mathfrak{b}$; the absorption being $\mathfrak{a} > \mathfrak{b}$. The formula for the absorption of the mineral is $\mathfrak{a} > \mathfrak{b} = \mathfrak{c}$. The color is very unevenly distributed, however, and in some crystals may be entirely lacking. It is generally arranged in zones, or in narrow bands parallel with the prism, and therefore parallel with the prismatic cleav-

age previously described. In fact, the bands of color and this cleavage stand in very close relation, the latter being far more readily seen in such crystals or portions of crystals as show the blue pleochroism. Between crossed nicols, the pleochroic and non-pleochroic portions of the crystal are optically continuous, but show a perceptible difference in double refraction. The fact that the pleochroic zones and bands are usually found on the peripheries of the larger crystals, suggested that the pleochroism might possibly be a secondarily derived property, but this is now thought doubtful.

In thin sections of the schist, the bright polarization colors and high relief of the mineral are decidedly striking. Pleochroism can very rarely be detected in slides of the ordinary thickness.

CHEMICAL COMPOSITION.

Two chemical analyses of lawsonite have been made, and are given below in tabular form, with their molecular ratios, the derived formula, and the theoretical composition.

TABLE SHOWING ANALYSES OF LAWSONITE, AND DERIVATION OF ITS CHEMICAL FORMULA.

	I.	Molecular Ratios.	Reduced Ratios.	II.	Molecular Ratios.	Reduced Ratios.	Mean of I and II.	Molecular Ratios.	Reduced Ratios.	Theoretical composition deduced from formula.
SiO_2	38.10	.635	1.92	37.32	.622	1.95	37.71	.628	1.93	38.09
Al_2O_3	28.88	.288	.87	35.14	.341	1.07	32.43	.314	.93	32.69
Fe_2O_3	.85									
CaO	18 26	.330	1.00	17.83	.318	1.00	18.15	.324	1.00	17.77
MgO	.23									
Na_2O	.65	.....	...	.....	...	...	. ....	...	...	.....
H_2O	11.42	.634	1.92	11.21	.622	1.95	11.31	.625	1.92	11.45
Totals	98.39	.....	...	101.50	...	...	99.60	...	...	100.00

Formula: $H_4CaAl_2Si_2O_{10}$.

Number I was made by the writer in the Geological Laboratory of the University of California, on selected crystal fragments, the powder being dried at 100° C.

Number II was carried out at the University of Munich by Dr. Palache on .7 gram of material obtained by crushing and purifying small crystals.

The cause of the difference between the two analyses is not known, and it is somewhat to be regretted that time does not permit of a third analysis on the more abundant and better material now at hand. However, as is shown in the foregoing table, either of the two analyses would lead to the same formula, while the mean of the two agrees quite closely with the theoretical composition. The water is undoubtedly constitutional as the loss after raising the powdered and dried mineral gradually up to a temperature of 225° C. (the highest attainable with the apparatus at hand), and keeping it so for over an hour, was only a little over 0.1 *per cent.* The following is suggested as the probable structural formula:—

$$\begin{matrix} (HO)_2=Al \\ \qquad\quad Ca \\ (HO)_2=Al \end{matrix} \Big\rangle SiO_3$$

GENERAL PHYSICAL PROPERTIES AND BLOWPIPE REACTIONS.

The color of lawsonite resembles that of rather pale kyanite. Small perfectly fresh crystals are generally clear and colorless, but others, and especially the larger individuals, show a gray-blue color that is unevenly distributed through their mass, much as in kyanite. In weathering, the mineral suffers a loss of transparency and becomes gray, or mottled with grayish and milky white patches. The luster is vitreous, with a suggestion of greasiness. Its great hardness is one of its most remarkable physical properties, and is about 8 in terms of Moh's scale. It scratches topaz readily, but is in turn scratched by the latter mineral, and is apparently of the same degree of hardness. It is markedly brittle.

The specific gravity as determined by the chemical balance is 3.084. The powdered mineral as separated from the schist was found to remain suspended in Thoulet solution of 3.091 specific gravity (Palache).

Before the blowpipe the mineral fuses readily at 2.5 to 3 of Von Kobell's scale, with swelling and exfoliation to a white or light gray vesicular glass, and gelatinizes readily with hydrochloric acid after fusion. The unfused mineral is only slightly acted upon by boiling with concentrated hydrochloric acid, but is completely decomposed with the separation of gelatinous silica by heating it in a sealed tube with the same acid for eight hours, at a temperature of 140° C. Abundant water is given off in a matrass at a red heat, and does not react acid. With cobalt nitrate it gives the reaction for alumina, and affords a silica skeleton in a salt of phosphorus bead.

PLACE OF LAWSONITE IN CLASSIFICATION.

It will be seen that the new mineral falls into the second division of the subsilicates as classified by Dana in the last edition of the "System of Mineralogy," having an oxygen ratio of 2 : 3, and thereby suggesting some highly interesting analogies with the mineral carpholite. The latter has a composition of $H_4MnAl_2Si_2O_{10}$, the water being constitutional, and is regarded by Groth as a basic metasilicate. Lawsonite differs from it in composition by having the manganese replaced by calcium. Carpholite is said to crystallize in the monoclinic system, but there appears to be some doubt of this fact. The similarity in chemical composition and the probable identity of molecular structure is suggestive of the possibility of the two minerals being isomorphous, and the suggestion is strengthened somewhat by the inconsiderable difference in the prism angles, that of carpholite being 68° 33′, while the acute prism angle of lawsonite is 67° 16′.

Carpholite is optically negative, while lawsonite is positive. In regard to general habit, too, and physical properties, carpholite appears to be very different from lawsonite, but the comparison of the two is certainly interesting and suggestive.

ASSOCIATED MINERALS.

The most abundant mineral immediately associated with the lawsonite is the lustrous greenish-white micaceous mineral, in which most of the larger crystals are embedded. The folia are small, two or three millimeters in diameter, decidedly brittle, and possessing a

brilliant, somewhat pearly luster. Before the blowpipe they fuse easily, and answer well to the characters of margarite. A very little water is given off by strongly heating in a matrass. Cleavage flakes show the emergence of a negative acute bisectrix on the basal plane, with a large axial angle. This mineral occurs mainly filling veins in the schist, and inclosing crystals of lawsonite with occasional masses and crystals of pyrite.

A light-colored epidote is also very abundant in certain portions of the schist, in aggregations of small crystals, forming streaks and bands through the rock in the direction of schistosity. The color varies from pale greenish yellow to almost ash gray. The lens shows that the crystals are columnar in habit, without distinct terminations, with the faces finely striated longitudinally, and possessing a perfect cleavage in a plane parallel with the axis of elongation. Before the blowpipe, the mineral fuses with intumescence to a dark brown slag, which readily gelatinizes with acids, the solution reacting for lime, alumina, and ferric oxide. The specific gravity, determined by suspending particles in Klein's solution, is 3.326.

Cleavage flakes show a biaxial figure, of which one hyperbola only appears in the field. The plane of the optic axes is transverse to the direction of crystallographic elongation, and the optical sign is negative. This corresponds with the usual orientation of the axes in epidote. The dispersion is $\rho < v$. Cross sections (clinopinacoidal) of the crystals are generally irregular in outline, but occasionally show the hexagonal contour, and inclined extinction of epidote. Such sections give no interference figure. The cleavage is not so conspicuous in micro-sections as would be expected, and in clinopinacoidal sections is difficult to detect. Cleavage flakes, and sections which are not too thin, exhibit distinct pleochroism, **c** pale greenish yellow, **b** fainter yellow, and **a** colorless or grayish, the absorption being $\mathbf{c} > \mathbf{b} > \mathbf{a}$. The index of refraction is high, but the double refraction is not conspicuously strong, the colors between crossed nicols rarely mounting above those of the amphibole minerals in the same slide.

The conclusion from the foregoing description is that the mineral is an epidote poor in iron and closely approaching zoisite in composition, the poverty in iron accounting for the pale color, faint

pleochroism, low specific gravity, and comparatively weak double refraction. Although the latter is generally extremely strong in epidote, yet observations show that it may vary between wide limits,* and there seems to be no necessary reason why epidote and zoisite should not show gradations in this respect somewhat comparable with the known gradations in chemical composition.

The remaining minerals which occur with lawsonite, as constituent minerals of the schist, are actinolite, glaucophane, and abundant small red garnets in crystals up to about 3 mm. in diameter. These minerals are very variously distributed in different portions of the same mass of schist, so that the latter appears green, blue, yellowish green or red according to the local preponderance of actinolite, glaucophane, epidote, or garnet respectively. The glaucophane is not deeply colored, the color being rather unevenly distributed, and has the usual pleochroism, **a** light yellow, **b** light violet, and **c** deep sky blue. The relation $\mathfrak{c} : c = 13° — 15°$ was established by means of the quartz wedge, and by reading the extinction angles of sections whose pleochroism showed them to be approximately paralled with the axial plane. The smaller angle given above, which is regarded as being nearest the true one, is twice as great as that given for typical glaucophane, but Hintze† cites similar cases of large extinction angles observed by Schluttig, Koto, and Stelzner. In this case it is probably due to some isomorphous admixture of the actinolite molecule, and is in full accord with the modern conception, that the minerals of the amphibole group form a continuous series whose members are composed of isomorphous molecules in varying proportions.

Microscopic sections also show the presence of chlorite and small, highly refracting crystals and grains of titanite. The chlorite is in most cases clearly a decomposition product of garnet.

Geological Laboratory,
University of California, May, 1895.

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* Rosenbusch. Mikroskopische Physiographie, 2d ed., p. 497.

† Handbuch der Mineralogie, p. 1258.

EXPLANATION OF PLATE 17.

$m = \{110\}$
$d = \{011\}$
$d' = \{041\}$
$o = \{001\}$
$b = \{010\}$

Figure 1.—Common habit of lawsonite when crystallizing freely in open clefts.

Figure 2.—Frequent habit of small crystals.

Figure 3.—Crystal fragment, showing occurrence of the rare brachydome face $d' = 041$.

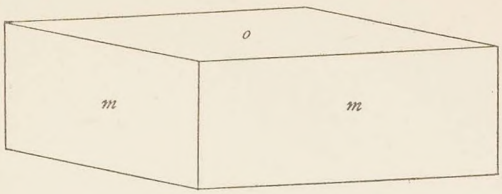
Figure 4.—Diagrammatic plan of twin crystal, showing striæ on basal pinacoids, positions of axial planes, and reëntrant angle.

Figure 5.—Twin of the habit common in larger crystals embedded in margarite. Twinning and composition plane the prism.

Figure 6.—Habit commonly affected by larger crystals embedded in margarite, showing characteristic direction of elongation.

Figure 7.—Habit of large crystals in matrix of margarite.

Figure 8.—Twin of the habit common in smaller crystals.



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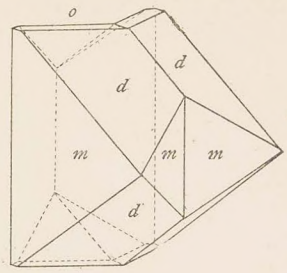

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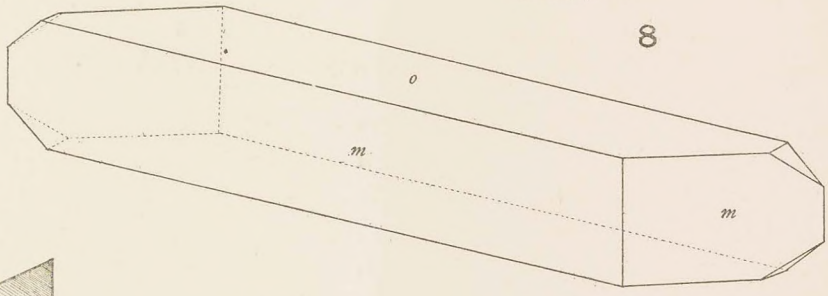

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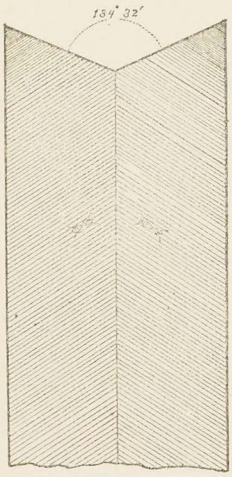

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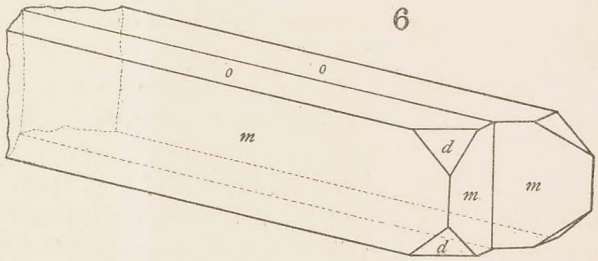

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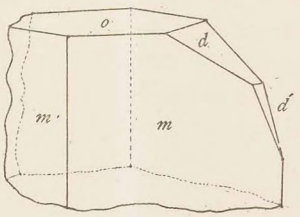

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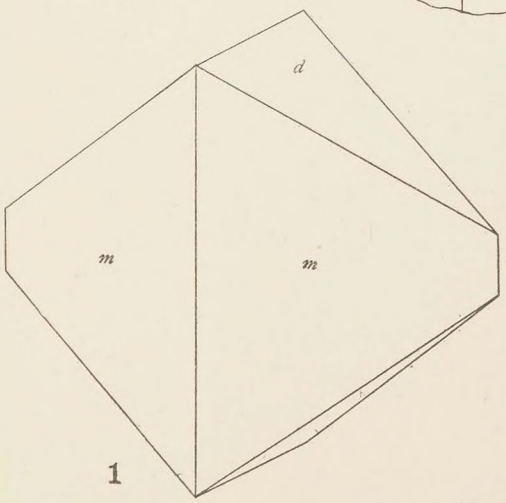

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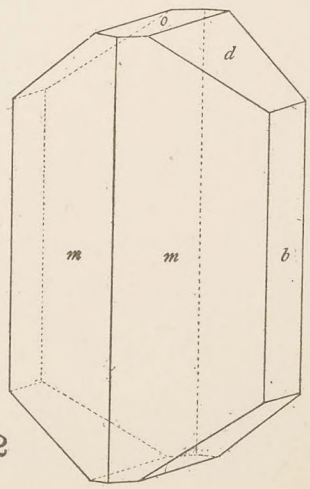

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Lawsonite

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